CLAIMS

Sub Q50

1. A laser device which generates ultraviolet light, characterized by comprising:

a laser light generator section which generates mono-wavelength laser light in a wavelength range of from an infrared region to a visible region;

an optical amplifier section including an optical fiber amplifier which amplifies the laser light generated by the laser light generator section; and

a wavelength conversion section which includes a plurality of nonlinear optical crystals which perform wavelength conversion of the laser light amplified by the optical amplifier section, and a plurality of temperature controllers which perform temperature control of the plurality of the nonlinear optical crystals to tune phase matching angles at the time of wavelength conversion, wherein

the wavelength conversion section generates ultraviolet light.

3
~~2~~. A laser device which generates ultraviolet light, characterized by comprising:

a laser light generator section which generates mono-wavelength laser light in a wavelength range of from an

infrared region to a visible region;

an optical amplifier section including an optical fiber amplifier which amplifies the laser light generated by the laser light generator section; and

a wavelength conversion section which performs wavelength conversion of the laser light amplified by the optical amplifier section into ultraviolet light by using a plurality of the nonlinear optical crystals, wherein

a lithium tetraborate ($Li_2B_4O_7$) crystal is used for at least one of the plurality of the nonlinear optical crystals.

4 ~~3~~. A laser device as recited in claim 3 ~~2~~, characterized in that

the wavelength conversion section generates an eighth-order harmonic wave as ultraviolet light from a fundamental wave of the laser light and a seventh-order harmonic wave thereof according to sum frequency generation, and

a lithium tetraborate ($Li_2B_4O_7$) crystal is used for a portion which generates the eighth-order harmonic wave.

5 ~~4~~. A laser device as recited in claim 3 ~~2~~, characterized in that

the plurality of the nonlinear optical crystals

includes a nonlinear optical crystal for which a GdYCOB crystal is used, in addition to the nonlinear optical crystal for which the lithium tetraborate crystal is used.

6 ~~5~~. A laser device which generates ultraviolet light, characterized by comprising:

a laser light generator section which generates mono-wavelength laser light in a wavelength range of from an infrared region to a visible region;

an optical amplifier section including an optical fiber amplifier which amplifies the laser light generated by the laser light generator section; and

a wavelength conversion section which performs wavelength conversion of the laser light amplified by the optical amplifier section into ultraviolet light by using a plurality of nonlinear optical crystals, wherein

a KAB ($K_2Al_2B_4O_7$) crystal is used for at least one of the plurality of the nonlinear optical crystals.

7 ~~6~~. A laser device as recited in claim 6 ~~5~~, characterized in that

the plurality of the nonlinear optical crystals includes a nonlinear optical crystal for which the GdYCOB ($Gd_xY_{1-x}Ca_4O(BO_3)_3$) crystal is used, in addition to the nonlinear optical crystal for which the KAB crystal is used.

8 ~~7~~. A laser device as recited in claim 6 ~~5~~, characterized in that

the wavelength conversion section generates an eighth-order harmonic wave from a fundamental wave of the laser light and a seventh-order harmonic wave thereof according to sum frequency generation, and

a KAB crystal is used for a portion which generates the eighth-order harmonic wave.

9 ~~8~~. A laser device as recited in claim 6 ~~5~~, characterized in that

the wavelength conversion section generates an eighth-order harmonic wave from a fourth-order harmonic wave of the laser beam according to second-order harmonic generation, and

a KAB crystal is used for a portion which generates the eighth-order harmonic wave.

10 ~~9~~. A laser device which generates ultraviolet light, characterized by comprising:

a laser light generator section which generates mono-wavelength laser light in a wavelength range of from an infrared region to a visible region;

an optical amplifier section including an optical fiber amplifier which amplifies the laser light generated by the laser light generator section; and

a wavelength conversion section which performs

wavelength conversion of the laser light amplified by the optical amplifier section into ultraviolet light by using a plurality of nonlinear optical crystals, wherein

a GdYCOB ($Gd_xY_{1-x}Ca_4O(BO_3)_3$) crystal is used for at least one of the plurality of the nonlinear optical crystals.

~~10~~ 11. A laser device as recited in claim ~~9~~ 10, characterized in that

the wavelength conversion section includes a portion which generates a fourth-order harmonic wave from a second-order harmonic wave of the laser light,

a GdYCOB crystal is used for the portion which generates the fourth-order harmonic wave, and the GdYCOB crystal generates the fourth-order harmonic wave according to non-critical phase matching.

~~11~~ 12. A laser device which generates ultraviolet light, characterized by comprising:

a laser light generator section which generates mono-wavelength laser light in a wavelength range of from an infrared region to a visible region;

an optical amplifier section including an optical fiber amplifier which amplifies the laser light generated by the laser light generator section; and

a wavelength conversion section which performs

wavelength conversion of the laser light amplified by the optical amplifier section into ultraviolet light by using a plurality of nonlinear optical crystals , and which includes the plurality of relay optical systems which relay the laser light among the plurality of the nonlinear optical crystals, wherein

the plurality of the relay optical systems are each disposed to allow light of one wavelength to pass through.

~~12~~ 13. A laser device as recited in claim ~~11~~ 12, characterized in that

the wavelength conversion section generates an eighth-order harmonic wave from a fundamental wave and a seventh-order harmonic wave thereof, and

when generating the seventh-order harmonic wave, the wavelength conversion section uses the sum frequency generation of two light waves of fundamental, second-order harmonic, fifth-order harmonic, and sixth-order harmonic waves to generate the seventh-order harmonic wave.

~~13~~ 14. A laser device which generates ultraviolet light, characterized by comprising:

a laser generator section which generates mono-wavelength laser light in a wavelength range of from an

infrared region to a visible region;

an optical splitter section which splits the laser light generated by the laser generator section into a plurality of luminous fluxes;

a plurality of optical amplifier sections which amplifies each of the plurality of luminous fluxes split by the optical splitter section by using an optical fiber amplifier; and

a wavelength conversion section which performs wavelength conversion of laser light of a bundle of the plurality of the luminous fluxes from the plurality of the optical amplifier sections into ultraviolet light by using a plurality of nonlinear optical crystals, wherein

the wavelength conversion section includes a nonlinear crystal which generates a harmonic wave according to sum frequency generation of a first beam composed of a fundamental wave or a harmonic wave of the laser light and a second beam composed of a harmonic wave of the laser light, and

an anisotropic optical system having magnifications which are different in two directions crossing with each other to match the individual magnitudes of the plurality of the luminous fluxes composing the first beam to the individual magnitudes of the plurality of the luminous fluxes composing the second beam.

~~14~~ 15. A laser device as recited in claim ~~13~~ 14, characterized in that

the anisotropic optical system is either a cylindrical-lens array including the same number of lens elements as that of the plurality of the luminous fluxes composing the laser beam or a prism array.

~~15~~ 16. A laser device as recited in any one of claims ~~11~~ 12 to ~~14~~ 15, characterized in that

the ultraviolet light has a wavelength of about 200 nm or shorter, and one of lithium tetraborate and KAB crystals is used for a last-stage nonlinear optical crystal of the plurality of the nonlinear optical crystals which generates the ultraviolet light.

~~16~~ 17. A laser device as recited in claim ~~15~~ 16, characterized in that

a GdYCOB crystal is used for at least one nonlinear optical crystal which is different from the last-stage nonlinear optical crystal.

~~17~~ 18. A laser device which generates ultraviolet light, characterized by comprising:

a laser generator section which generates mono-wavelength laser light;

an optical amplifier section including an optical fiber amplifier which amplifies the laser light; and

a wavelength conversion section which performs wavelength conversion of the amplified laser light into ultraviolet light having a wavelength of about 200 nm or shorter by using a plurality of nonlinear optical crystals, wherein

one of lithium tetraborate and KAB crystals is used for a last-stage nonlinear optical crystal of the plurality of the nonlinear optical crystals which generates the ultraviolet light.

19 ~~18~~. A laser device as recited in claim 16 ~~17~~, characterized in that

a GdYCOB crystal is used for at least one nonlinear optical crystal which is different from the last-stage nonlinear optical crystal.

20 ~~19~~. A laser device as recited in any one of claims 1 to 13 ~~12~~, 18 ~~17~~ and 19 ~~18~~, characterized by further comprising

an optical splitter section which splits the laser light generated by the laser generator section into a plurality of

laser beams, wherein

the optical amplifier sections are independently provided for the plurality of split laser beams, respectively, and

the wavelength conversion section collects fluxes of laser beams output from the plurality of the optical amplifier sections and performs wavelength conversion thereof.

~~20~~ 21. A laser device as recited in any one of claims 1 to ~~14~~ 15, ~~17~~ 18 and ~~18~~ 19, characterized in that

the laser generator section generates a mono-wavelength laser light having a wavelength of near 1.5 μm, and

the wavelength conversion section converts a fundamental wave having the wavelength of near 1.5 μm output from the optical amplifier section into ultraviolet light of one of an eighth-order harmonic wave and a tenth-order harmonic wave, and outputs the ultraviolet light.

21. A laser device as recited in any one of claims 1 to ~~14~~ 15, ~~17~~ 16 and ~~18~~ 19, characterized in that

the laser generator section generates a mono-wavelength laser light having a wavelength of near 1.1 μm, and

the wavelength conversion section converts a fundamental wave having the wavelength of near 1.1 μm output from the optical amplifier section into ultraviolet light of one of an eighth-order harmonic wave and a tenth-order harmonic wave, and outputs the ultraviolet light.

from the optical amplifier section into ultraviolet light of a seventh-order harmonic wave, and outputs the ultraviolet light.

22. An exposure method which uses ultraviolet light generated by the laser device as recited in any one of claims 1 to 14, 17 and 18, characterized in that

the ultraviolet light is incident onto a mask, and a substrate is exposed with the ultraviolet light passed through a pattern of the mask.

23. An exposure apparatus, characterized by comprising:

a laser device as recited in any one of claims 1 to 14, 17 and 18,

an illumination system which irradiates a mask with ultraviolet light from the laser device, and

a projection optical system which projects an image of a pattern of the mask onto a substrate, wherein

the substrate is exposed with the ultraviolet light passed through the pattern of the mask.

24. A manufacturing method of an exposure apparatus which illuminates a mask with ultraviolet light, and which exposes a substrate with the ultraviolet light passed through a

pattern of the mask, characterized in that

a laser device as recited in any one of claims 1 to ~~14~~ 15, ~~17~~ 16 and ~~18~~ 19,

an illumination system which irradiates a mask with ultraviolet light from the laser device, and

a projection optical system which projects an image of a pattern of the mask onto a substrate, are disposed with a predetermined relationship.

~~25~~ 23. A device manufacturing method including a step of transferring a mask pattern onto a substrate through use of the exposure method as recited in claim 22.